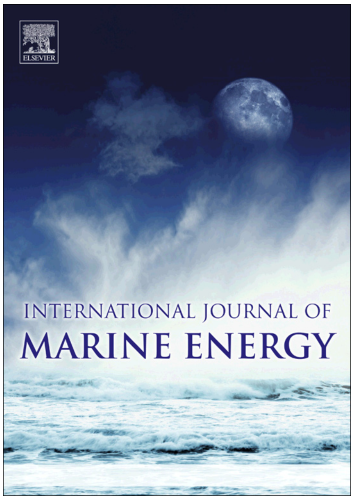

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PII: S2214-1669(17)30001-2
DOI: http://dx.doi.org/10.1016/j.ijome.2017.01.001
Reference: IJOME 132

To appear in:

Received Date: 22 April 2016
Revised Date: 18 October 2016
Accepted Date: 11 January 2017

Please cite this article as: P. Pyakurel, J.H. VanZwieten, M. Dhanak, N. Xiros, Numerical modeling of turbulence and its effect on ocean current turbines, (2017), doi: http://dx.doi.org/10.1016/j.ijome.2017.01.001

Numerical modeling of turbulence and its effect on ocean current turbines

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Abstract

An approach for numerically representing turbulence effects in the simulation of Ocean Current Turbines (OCT)s is described. Ambient turbulence intensity and mean flow velocity are utilized to develop analytic expressions for flow velocities at a grid of nodes that are a function of time. This approach is integrated into the numerical simulation of an OCT to evaluate effects of turbulence on performance. For a case study a moored OCT with a 20 m rotor diameter is used. Mean power in the presence of ambient turbulence intensities (TI)s of 5% and 20% are found to be 370 kW and 384 kW, with standard deviations of 17.2 kW and 74.6 kW respectively. Similarly, the axial loads on a single blade of the three-bladed rotor are found to be 139 kN and 140 kN, with standard deviations of 3 kN and 12 kN respectively for these TIs.

Keywords: Turbulence, Inertial subrange, Ocean Current Turbine, Kolmogorov's 5/3 law, Turbulence Intensity, Hydrokinetic power

1. INTRODUCTION

Ocean currents represent a significant source of marine hydrokinetic energy that may be harnessed and converted to electricity using Ocean Current Turbines (OCT)s [1]. Based on the HYbrid Coordinate Ocean Model (HYCOM) model [2], ocean currents occur over a total area of 836,000 km^2 worldwide with average energy densities greater than 0.5 kW/m^2 at a depth of 50 m [3]. In the US, electricity production based on ocean currents has a technically extractable potential of 163 TWh/year [4], which is equivalent to 4% of 2014 US electricity production [5]. Off Florida, the time-averaged ocean current energy density can exceed 3.0 kW/m^2 [6]. Prototype OCTs have been developed to harness this resource and tested offshore [7]. Research and development of OCTs is also being carried out with the goal of producing power from the Kuroshio Current off Japan and Taiwan [8].

Turbulence causes fatigue loadings on these devices and longitudinal turbulence has been found to be a primary fatigue load driver for horizontal-axis tidal turbines [9]. Ambient turbulence is also found to impact the wake profile produced by the turbines [10, 11]. Since wake propagation characteristics will affect the velocity experienced by downstream turbines in an OCT farm, turbulence plays an important role in optimization of the turbine layout on the farm.

The simulation tool TurbSim was developed by National Renewable Energy Laboratory (NREL) to generate turbulent inflow simulations based on a given set of initial boundary conditions using ensemble statistics [12]. This tool treats turbulent flow velocity as a stationary signal that has a constant mean and standard deviation if the sampling period is sufficiently large. Spectra of velocity components and spatial coherence are defined in the frequency domain, and an inverse Fourier transform is used to generate velocity time histories. The generated time history can then be integrated into the turbine simulation tool Aerodyn [13]. Thus, a time history of the flow field is created prior to running turbine simulations.

Marine turbines have been found to be most sensitive to turbulence with frequencies below about 1 Hz [14]. The frequencies where a turbine will have a strong response is therefore likely to fall within and also extend below the inertial subrange, which is generally accepted to be in the frequency range of 0.2 Hz to 2 Hz [15]. Inertial subrange is the part of the wave-number spectrum where the rate of energy transfer through the spectrum is dominant compared to the rate of supply and dissipation of turbulent energy [16]. Furthermore, energy is transferred from larger scale eddies to smaller scale eddies with negligible viscous dissipation [17]. Turbulence energy spectrum within the inertial subrange can be generalized to be inversely proportional to the 5/3 power of frequency [18]. Vertical flow motions at frequencies lower than 0.2 Hz in tidal areas of interest are likely suppressed due to the constraints in vertical excursions imposed by the shallow water depth of the region [1515]. In water depths of 100 m+ depth where an OCT may operate, these bottom boundary effects are not significant. Therefore, the flow structure will be more three-dimensional and